BRAKE ACTUATOR WITH INTEGRAL ANTILOCK MODULATOR

Background of the Invention

[0001] This invention relates to the art of brake systems for heavy vehicles and, more particularly, to anti-lock brake systems for vehicles such as truck tractors and tractor-trailer combinations that use brake actuators and antilock modulators.

[0002] Antilock brake systems (ABS) have been provided for heavy vehicles, such as truck tractors, trucks, and buses, which have plural axles and one or more wheels supported at the end of each axle. Generally, adjacent each wheel is a brake actuator adapted to engage a brake assembly that is part of or adjacent a wheel to effect the deceleration thereof. Typically, brake actuators are only a portion of an overall antilock brake system, and such brake systems further include an operator interface, such as a foot-actuated pedal, a reservoir containing a quantity of pressurized braking fluid (commonly pressurized air), one or more relay valves and, in antilock braking systems, one or more modulators. It will be appreciated that a considerable amount of brake line is necessary to fluidically interconnect each of these many components of the brake system. It will be further appreciated that these components are mounted on various parts of the vehicle and may be a considerable distance from one another, especially in braking systems on tractor-trailer combinations.

[0003] In addition to these mechanical components, antilock brake systems include various electronic control components, including an electronic control unit (ECU) and one or more speed sensors monitoring the rotational speed of the wheels. Furthermore, the modulators typically include an electro-mechanical interface that uses electrical signals to actuate a mechanical valve.

[0004] It will be appreciated that **FIGURES 1 and 2**, respectively, illustrate a conventional antilock braking system and brake actuator for use on a vehicle, such as a truck tractor. Such antilock braking systems and brake actuators are generally known by those

skilled in the art, and the following discussion of **FIGURES 1 and 2** is merely provided to establish background environment and terminology for further discussion of the illustrated embodiments of the present invention.

[0005] **FIGURE 1** illustrates a conventional antilock braking system **10** operatively associated with a vehicle (not shown) that has plural axles **AX** and at least one wheel **WL** on the axles. Antilock brake system **10** includes a reservoir **12** for storing a quantity of pressurized brake fluid, such as compressed air, which is conveyed to the reservoir by compressor **14** through supply line **16**. Relay valves **20** and **22** receive compressed air from the reservoir through primary supply lines **50** and **52**, respectively. Relay valve **20** communicates with modulator **30** through secondary supply line **60**, and relay valve **22** likewise communicates with modulators **32** and **34** through secondary supply line **62**. Modulator **30** selectively outputs either modulated or non-modulated compressed air to service brake actuators **102** through tertiary supply lines **70** and **72**. Likewise, modulators **32** and **34** selectively output compressed air to service brake actuators **102** and the service brake portion of spring brake actuators **100**. Modulator **32** supplies the actuators, **100** and **102**, on one side of the brake system, such as the left side, through tertiary supply lines **80** and **82**. Modulator **34** supplies compressed air to the actuators, **100** and **102**, on the opposite side of the system, such as at the right side, through tertiary supply lines **84** and **86**.

[0006] The antilock braking system **10** also includes an electronic control unit **90** for activating the antilock braking function of the system. In response to signals **96** received from wheel speed sensors **94**, electronic control unit **90** selectively outputs activation signals **98** to an electro-mechanical interface **92** of modulators **30, 32,** and **34** to effect the modulation, or pulsing, of the compressed air passing therethrough. It will be appreciated that electro-mechanical interface **92** of the modulators may include any suitable arrangement, such as one or more solenoid and valve assembly, for modulating or pulsing air through the antilock braking system.

[0007] Antilock braking systems of the foregoing nature include an operator interface **40** having an actuation pedal **42** and a control valve **44**. The control valve opens and closes in proportional response to the displacement of the actuation pedal by the operator. Control supply lines **46** extend between reservoir **12** and control valve **44**, and control delivery lines **48** extend between control valve **44** and relay valves **20, 22**. As such, compressed air flows from the reservoir to the relay valves upon opening of the control valve by the operator. The presence of pressurized air at the relay valves within the control delivery lines **48** causes a proportional opening of the relay valves, allowing compressed air to flow from the reservoir to the brake actuators and thereby apply the vehicle brakes. It will be appreciated that in other embodiments, the relay valves may be opened and closed by other types of control signals, such as electrical control signals, generated in response to a braking action of the operator.

[0008] **FIGURE 2** illustrates a conventional service brake actuator **102** generally known in the art. Service brake actuator **102** has a housing **110** formed by two housing portions **112** and **114**. Housing portion **112** includes an end wall **116** and a side wall **118** extending from the end wall and forming a cavity **120**. Housing portion **114** likewise has an end wall **122** and a side wall **124** defining a cavity **126**. Flanges **128** and **130** respectively extend from sidewalls **118** and **124**, and compressively engage an outer peripheral wall **134** of diaphragm **132**. Retaining member **136** extends around the exterior of the housing adjacent flanges **128** and **130**, and retains the housing portions in a compressive, air-tight relationship with a peripheral portion of the diaphragm **132**. The diaphragm isolates cavities **120** and **126** from one another, and end wall **122** includes a passage **140** in communication with cavity **126**.

[0009] The service brake actuator also includes a piston assembly **150** positioned within cavity **120**. The piston assembly has a push plate or plunger **152**, an actuator means **154** (e.g., an actuating rod) extending from the plunger and passing through end wall **116**, and a brake-engaging clevis **156** extending from actuator rod **154** outside of housing **110**. The brake actuator also includes a biasing member or spring **158** compressively positioned

within cavity **120** between end wall **116** and plunger **152**, retaining the plunger against diaphragm **132** and urging the actuator rod toward the interior of the brake actuator. Housing **112** also includes mounting hardware **160** for supporting the brake actuator on the vehicle. It will be appreciated that in operation, compressed air selectively enters the brake actuator from the braking system through passage **140**, filling cavity **126** and displacing piston assembly **150** such that actuator rod **154** extends from the housing and actuates the brake. Upon release of the pedal by the vehicle operator, the compressed air is vented by the braking system from cavity **126**, allowing spring **158** to again urge actuator rod **154** toward the interior of cavity **120**.

[0010] In use, an operator resides in the vehicle cab and selectively depresses actuation pedal **42** to effect the deceleration of the vehicle. In response to the displacement of the pedal, control valve **44** generates a proportional control signal in the brake system by providing a cooperably associated passage through the control valve such that compressed air can flow between reservoir **12** and relay valves **20, 22** through supply and delivery lines **46, 48**. The presence of the control signal delivered to relay valves **20, 22** through control delivery lines **48** causes the proportional opening of the relay valves to permit passage of compressed air from reservoir **12** to modulators **30, 32** and **34**, and ultimately to the service brake portion of spring brake actuators **100** and to service brake actuators **102**. Compressed air is supplied to relay valve **20** through primary delivery line **50** and proportionally passed through the relay valve to antilock modulator **30** through secondary delivery line **60**. Modulator **30** outputs the compressed air to service brake actuators **102** through tertiary delivery lines **70, 72**. Compressed air is also supplied to relay valve **22** from reservoir **12** through primary delivery line **52**, and is proportionally passed through the relay valve to antilock modulators **32, 34** through secondary delivery line **62**. Modulator **32** outputs the compressed air to the actuators, **100** and **102**, on one side of the vehicle, such as the left side, through tertiary delivery lines **80, 82**, and modulator **34** outputs compressed air to the actuators, **100** and **102**, on the other side of the vehicle, such as the right side, through tertiary delivery lines **84, 86**.

[0011] Each sensor **94** outputs a signal **96**, proportional to the rotational speed of its respective wheel, to the electronic control unit **90** which determines if any of the wheels **WL** have stopped rotating, or are rotating at a significantly different speed than the other wheels. In such case, the electronic control unit outputs antilock activation signals **98** to the electro-mechanical interface **92** of the appropriate antilock modulators. The modulators, in turn, modulate or pulse the compressed air flowing through the tertiary delivery line to the brake actuator thereby reducing or eliminating the locked wheel condition. It will be appreciated that the modulated air is generally present only in the tertiary delivery lines, such as lines **70**, **72**, **80**, **82**, **84** and **86**. It will be further appreciated that it is along these tertiary delivery lines that the attenuation of the modulated air occurs from which the reduced responsiveness of the antilock braking system results.

[0012] The spring brake actuators include a service brake portion and a parking brake portion. The service brake portion functions in the traditional manner to decelerate the vehicle in cooperation with the other service brake actuators. The parking brake portion prevents rotation of the wheels when the vehicle is in a parked condition and may also be applied and act as supplemental service braking under selected circumstances (not illustrated). It will be appreciated that the parking brake portion of the spring brake actuators also includes a parking brake control system for engaging and disengaging the parking brake portion of the spring brakes, and that such a control system is generally conventional and well known in the art so that it is not represented in the drawings or described in further detail herein.

[0013] Brake systems of the foregoing nature generally provide a system for reducing the distance required to decelerate a vehicle. However, such systems also have a number of disadvantages that make these systems expensive to manufacture and install, and which preclude the further increase in performance and reduction of stopping distance of vehicles.

[0014] One such disadvantage in such antilock braking systems is that one modulator is used to modulate or pulse the pressurized air delivered to two different brake actuators. As

such, the modulator is remotely mounted some distance away from each of the two brake actuators, and a separate brake line must be used to carry the pressurized air to each of the brake actuators. The compressibility and inertia of the air in the segment of brake line extending between the modulator and the brake actuator attenuates the braking pulses and leads to a reduced responsiveness of the braking system.

[0015] Another disadvantage of braking systems of the foregoing nature is that the modulators typically provide service to two separate brake actuators, and thus the modulators have an increased size to accommodate the air capacity required for a pair of brake actuators. Furthermore, each modulator is installed separately or remotely from the brake actuators to which it provides service. As such, additional costs and installation problems exist in mounting the modulator separately from the brake actuators and installing the brake line extending therebetween. It will be appreciated that in addition to the installation of the segments of brake line extending between the modulator and the two different brake actuators, these segments of line and the air-tight seals existing at both ends of each line must be checked and properly maintained to ensure the reliability of the braking system.

[0016] The present invention provides a new and improved apparatus and method which addresses the above-referenced problems.

Brief Summary of the Invention

[0017] In accordance with one embodiment of the present invention, a brake actuator for actuating a brake to decelerate a vehicle includes a housing defining a cavity and an integral modulator. An input passage communicates with a source of pressurized air and the modulator. An outlet passage communicates with the cavity and the modulator. The pressurized air passes from the input passage to the cavity via the modulator and the outlet passage. The modulator modulates the pressurized air passed to the cavity.

[0018] In one aspect of the invention, the modulator includes a solenoid that operates in a plurality of modes.

[0019] In another aspect of the invention, the modulator includes a supply diaphragm between the input passage and the outlet passage and an exhaust diaphragm between the outlet passage and an exhaust passage. The supply and exhaust diaphragms cooperate to modulate the pressurized air passed to the cavity.

[0020] In another aspect of the invention, the modulator includes a first valve, associated with the supply diaphragm, movable to a plurality of positions. The modulator operates in respective ones of a plurality of modes as a function of the position of the first valve. The pressurized air is passed from the input passage to the outlet passage while the modulator is operating in a first one of the modes.

[0021] In another aspect of the invention, the modulator includes a second valve, associated with the exhaust diaphragm, movable to a plurality of positions. The modulator operates in the respective ones of the plurality of modes as a function of the respective positions of the first and second valves.

[0022] In another aspect of the invention, a first solenoid selectively moves the first valve to the plurality of positions.

[0023] In another aspect of the invention, a second solenoid selectively moves the second valve to the plurality of positions.

[0024] In another aspect of the invention, the modulator includes an exhaust passage communicating with a face of the exhaust diaphragm. The pressurized air is passed from the outlet passage to the exhaust passage while the modulator is operating in a second one of the modes.

[0025] In another aspect of the invention, a speed sensor is associated with a wheel of the vehicle. A comparator determines a comparison of a speed of the vehicle to a speed of

the wheel. A modulation controller controls the first and second solenoids as a function of the comparison.

[0026] In accordance with another embodiment of the present invention, a brake actuator for a vehicle includes a housing defining a cavity, an input passage communicating with a source of pressurized air, an outlet passage communicating with the cavity, and a means for modulating the pressurized air received via the input passage and communicated to the cavity via the outlet passage.

[0027] In accordance with another embodiment of the present invention, a method for actuating a brake to decelerate a vehicle receives a compressed fluid into an input passage of a brake actuator. The compressed fluid is selectively modulated via a modulator integral with the brake actuator. The modulated compressed fluid is passed to a cavity of the actuator via a modulator outlet passage.

Brief Description of the Drawings

[0028] In the accompanying drawings which are incorporated in and constitute a part of the specification, embodiments of the invention are illustrated, which, together with a general description of the invention given above, and the detailed description given below, serve to exemplify the embodiments of this invention.

[0029] **FIGURE 1** is a schematic illustration of a conventional antilock braking system;

[0030] **FIGURE 2** is a side elevational view, partly in cross-section, of a conventional brake actuator;

[0031] **FIGURE 3** is a schematic illustration of an antilock braking system in accordance with a first embodiment of the present invention;

[0032] **FIGURES 4-7** are side elevational views, partly in cross-section, of a brake actuator having an integral antilock modulator in accordance with the first embodiment of the present invention;

[0033] **FIGURE 8** is a schematic illustration of an antilock braking system in accordance with a second embodiment of the present invention; and

[0034] **FIGURE 9** is a side elevational view, partly in cross-section, of a brake actuator having an integral antilock modulator in accordance with the second embodiment of the present invention.

Detailed Description of the Invention

[0035] Referring now in greater detail to the **FIGURES 3-9**, wherein the showings are for the purposes of illustrating various embodiments of the invention only, and not for the purpose of limiting the invention, **FIGURE 3** schematically illustrates an antilock braking system in accordance with a first embodiment of the invention. **FIGURES 4-7** illustrate a brake actuator with an integral antilock modulator in accordance with the first embodiment. Unless otherwise indicated, the items in **FIGURES 3-7** correspond to those illustrated and discussed in **FIGURES 1 and 2**. However, the items in **FIGURES 3-7** include reference numerals incremented by 200. That is, the reservoir **12** in **FIGURE 1** corresponds to item **212** in **FIGURE 3**, and the actuator housing **110** in **FIGURE 2** corresponds to item **310** in **FIGURE 4**. Items shown and described in one drawing figure, but having no counterpart in one or more of the other figures will be distinctly pointed out and discussed as deemed necessary.

[0036] As seen in **FIGURE 3**, pressurized air flows from reservoir **212** to relay valves **220, 222,** respectively, through primary delivery lines **250, 252**. The relay valves open and close proportionally in response to the control signal delivered through control delivery lines **248** from the control valve **244** of the operator interface **240**. As the relay

valves open, pressurized air flows therethrough in proportion to the displacement of actuation pedal **242**, and the pressurized air is delivered to the service portion of spring brake actuators **300** and to the service brake actuators **302** through secondary delivery lines **260, 262**. It will be appreciated that the secondary delivery lines **260, 262** carry the pressurized air directly to the brake actuators **300, 302**, and that the antilock modulators **30, 32** and **34** shown in **FIGURE 1** have no counterpart in **FIGURE 3**. It will be further appreciated that in addition to the elimination of the modulators shown in **FIGURE 1**, the tertiary delivery lines **70, 72, 80, 82, 84** and **86** shown in **FIGURE 1** have also been eliminated from the embodiment shown in **FIGURE 3**.

[0037] Speed sensors **294** in **FIGURE 3** output a signal **296** to the electronic control unit **290** which determines whether any of the wheels **WL** have stopped rotating or are rotating at a significantly different speed than the other wheels. As the electro-mechanical interfaces **92** illustrated in **FIGURE 1** have no counterpart in **FIGURE 3**, antilock activation signals **298** are output by the electronic control unit **290** directly to the integral electro-mechanical interfaces **304** of the integral antilock brake modulators of brake actuators **300, 302**. As such, the antilock modulation or pulsing of the pressurized air occurs at the brake actuator rather than at a remotely located and centralized modulator, such as those illustrated in **FIGURE 1**.

[0038] **FIGURE 4** illustrates a service brake actuator **302** in accordance with the first embodiment of the present invention having a housing **310** formed by two housing portions **312, 314**. Housing portion **312** includes an end wall **316** and a side wall **318** extending from the end wall and forming a cavity **320**. Housing portion **314** likewise has an end wall **322** and a side wall **324** defining a cavity **326**. Flanges **328, 330**, respectively, extend from side walls **318, 324**, and oppose one another compressively engaging an outer peripheral portion **334** of diaphragm **332**. Retaining member **336** extends around the exterior of the housing adjacent flanges **328, 330**, and retains the housing portions in a compressive, air-tight relationship with diaphragm **332**. The diaphragm seals or isolates cavities **320, 326** from one another, and integral antilock brake modulator **370** extends from end wall **322** and defines an

outlet passage **340** in communication with cavity **326** via a delivery passage (port) **344**. The modulator **370** also includes an exhaust passage (port) **346**. It will be appreciated by those skilled in the art that the antilock brake modulator **370** illustrated in **FIGURES 4-7** includes a three-way valve. However, other types of antilock brake modulator assemblies **370** are also contemplated.

[0039] Inlet passage **342** is adapted to connect to and form an air-tight seal with one of secondary delivery lines **260** and **262**. Pressurized air flows through the secondary delivery lines through inlet passage **342** and into an input passage **348**. The delivery passage **344** extends between the passage **340** and cavity **326**. Exhaust passage **346** extends through the housing **310** to ambient atmosphere.

[0040] The inlet passage **342** communicates through the passage **348** with a first or supply diaphragm **372**. The supply diaphragm is normally biased via a spring **374** toward a closed position with valve seat **376**. This prevents communication between the supply port **342** and the delivery passage **344**. As shown in **FIGURE 4**, when the brake valve is open and provides pressurized air to the inlet passage **348**, the closing bias of the spring **374** is overcome and the supply diaphragm is moved away from the valve seat **376** to provide pressurized air to the delivery passage **344**. This allows application of the brakes during what is referred to as normal service braking for decelerating the vehicle.

[0041] During normal service braking, pressurized air flows from the reservoir **212** through the primary delivery lines **250, 252** and into the secondary delivery lines **260, 262** as the relay valves **220, 222** are opened in proportion to the signal received from the operator interface. The pressurized air flows through the secondary delivery lines **260, 262** and into the inlet passage **342** and the passage **348**. The pressurized air then passes to the delivery passage **344** and the cavity **326** to displace the piston assembly **350** and move the actuator rod **354** out of the housing **310** to actuate the brakes and thereby decelerate the vehicle. Throughout the braking operation, each wheel speed sensor **294** provides a signal **296** to the electronic control unit **290** that is proportional to the speed of each respective wheel **WL**. If

necessary, the electronic control unit **290** outputs an antilock brake actuation signal **298** to the input terminal **382** of the appropriate brake actuators initiating the antilock braking operation of the braking system, which is discussed in more detail below with reference to **FIGURES 6 and 7**.

[0042] In addition, an exhaust diaphragm **378** is urged by spring **380** toward a closed position against valve seat **384**. This prevents communication of the pressurized air that enters the modulator past valve seat **376** to the delivery passage **344** with an exhaust passage **386** that leads to the exhaust passage **346**. Thus as shown in **FIGURES 4 and 5**, the exhaust diaphragm is disposed in a closed position. As will be recognized, when the supply diaphragm is moved away from the valve seat **376** during a service brake application, pressurized air is also provided through pilot passage **388** to a first exhaust solenoid valve **390**. Particularly, the passage **388** communicates with a pusher member (valve) **392**, particularly a first end **394**, of the solenoid valve. As shown in **FIGURES 4 and 5**, the pusher member **392** is biased or urged by spring **396** toward a normally open position allowing communication between passage **388** and passage **398** that communicates with the exhaust diaphragm **378**. Alternatively, when coil **400** of the solenoid valve is energized, the pusher member is urged toward a closed position preventing communication between flow passages **388, 398**. When the brakes are applied during normal service application, pressurized air from pilot passage **388** communicates through the first solenoid **390**, through the passage **398** and, along with the spring **380**, urges the exhaust diaphragm toward a closed position. This provides a pressure assist to urge the diaphragm valve toward a closed position during normal service brake application.

[0043] As will be further recognized from **FIGURES 3 and 4**, passage **388** also communicates with a second or supply solenoid valve assembly **401** and supply passage **348**. A pusher member (valve) **402** of the second solenoid is urged by spring **403** toward a normally closed position against valve seat **404**. That is, the flow passage **388** and supply passage **348** cannot communicate with the opposite face of the diaphragm **372** unless the coil **405** moves the pusher member against the force imposed by the spring. Instead, a pilot

passage **406** connects the supply diaphragm with the exhaust port through the second solenoid valve assembly **401**, and through passage **407**.

[0044] Although not particularly shown, it will be understood that a rapid exhaust is provided when the exhaust diaphragm **378** is urged away from its seat **384** and the brake port **344** is in communication with the exhaust port **346**. In that arrangement, the brake actuators are quickly released as the pressure exits the brake chamber through the exhaust passage **386** to port **346**.

[0045] **FIGURES 6 and 7** represent the same modulator valve structure as referenced with respect to **FIGURES 3 and 4**, and will be briefly described herein to provide an indication of the ABS operation. As indicated above, the first or exhaust solenoid valve **390** is urged toward a normally open position. The second or supply solenoid valve **401** is urged toward a normally closed position. In response to an antilock activation signal **298** received through input terminal **382**, the coils **400, 405**, associated with the first and second solenoid valve assemblies **390, 401**, respectively, are selectively energized to urge the respective pusher members **392, 402** to overcome the bias of the springs. Thus as shown in **FIGURE 6**, the second solenoid valve **401** is energized. This provides communication between pilot passage **388** and passage **348** and passage **407**, moving the diaphragm **372** to a closed position so that a constant air pressure is provided to the delivery port **344**.

[0046] **FIGURE 7** illustrates the energization of the first solenoid assembly (while the second solenoid valve assembly also remains energized) which closes off communication between passage **388** and passage **398**. In this manner, the exhaust diaphragm **378** is urged away from its valve seat **384** thus allowing the delivery port **344** to communicate with the exhaust port **346**. The actuation of the brakes on the vehicle are modulated or pulsed to provide controlled braking of the wheels **WL**.

[0047] It will be appreciated that the modulated or pulsed air directly enters the cavity through the delivery passage rather than having to first flow from a remotely located modulator through tertiary delivery lines to the actuator. As such, the reduced

responsiveness of the system due to the attenuation of the modulated or pulsed air flowing through the tertiary delivery lines encountered in prior art arrangements is eliminated.

[0048] **FIGURE 8** illustrates an alternate embodiment of the antilock braking system shown in **FIGURE 3**, and **FIGURE 9** illustrates an alternate embodiment of the brake actuator having an integral antilock modulator shown in **FIGURE 4**. Unless otherwise indicated, the items in **FIGURES 8 and 9** correspond to those illustrated in and discussed with respect to **FIGURES 3-7**. However, the items in **FIGURES 8 and 9** include reference numerals incremented by 200. For example, the reservoir **212** in **FIGURE 3** corresponds to item **412** in **FIGURE 8**, and the actuator housing **310** in **FIGURE 4** corresponds to item **510** in **FIGURE 9**. Items shown and described in one drawing figure, but having no counterpart in one or more of the other figures will be distinctly pointed out and discussed as deemed necessary.

[0049] As discussed with regard to **FIGURE 3**, modulators **30, 32** and **34**, and tertiary delivery lines **70, 72, 80, 82, 84** and **86** have no counterpart in antilock braking system **410** shown in **FIGURE 8**. Furthermore, the electronic control unit **90** illustrated in both **FIGURES 1 and 3** has no counterpart in **FIGURE 8** and, as such, antilock activation signals **98** likewise have no counterpart in **FIGURE 8**. Rather, **FIGURE 8** illustrates an antilock braking system **410** operatively associated with a vehicle having an engine **EG** and a transmission **TR**. The vehicle also includes a vehicle control module **VC** that receives vehicle output signals **VO** from the engine and the transmission. It will be appreciated, that the vehicle output signals include a signal indicating the overall speed of the vehicle, and that the vehicle control module **VC** communicates a vehicle speed signal **VS** to the integral electro-mechanical interface **504** of each brake actuator **500, 502**. Additionally, wheel speed sensors **494** output signals **496** proportional to the rotational speed of each respective wheel, and the signals **496** are also communicated to the electro-mechanical interface **504** of each respective brake actuator.

[0050] As is shown in **FIGURE 9**, brake actuator **502** includes a housing **510** having a first housing portion **512** and a second housing portion **514**. The actuator includes a diaphragm **532** and a piston assembly **550** assembled in association with the two housing portions as discussed above. The brake actuator **502** also includes an integral antilock brake modulator **570** extending from housing portion **514**. The modulator **570** has a passage **540** as discussed hereinbefore. The modulator **570** further includes a modulation controller **582p** having a signal comparator, such as a micro-processor. Input terminals **582** are in electrical communication with the modulation controller **582p**. The input terminals **582** receive a vehicle speed signal **VS** and a speed sensor output signal **496**. The micro-processor compares the signals **VS** and **496**, and selectively outputs antilock brake activation signals **498** to the solenoid valves **590, 601** when a determination is made that the wheel has stopped rotating or is rotating at a different relative speed than another wheel of the vehicle as indicated by vehicle speed signal **VS**. In response, the solenoid is energized and de-energized in rapid succession to modulate or pulse the pressurized air entering the brake actuator and thereby eliminate the locked wheel condition. As discussed hereinbefore with regard to **FIGURE 4**, modulator **570** of **FIGURE 9** typically includes a pair of solenoid valve assemblies.

[0051] While the invention has been described with reference to the preferred embodiments and considerable emphasis has been placed herein on the structures and structural interrelationships between the component parts of the embodiments disclosed, it will be appreciated that other embodiments of the invention can be made and that many changes can be made in the embodiments illustrated and described without departing from the principles of the invention. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. Accordingly, it is to be distinctly understood that the foregoing descriptive matter is to be interpreted merely as illustrative of the present invention and not as a limitation. As such, it is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.